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(12) (19) (CA) **Demande-Application**

E2-DF

(21) (A1) **2,260,565**
(22) 1999/01/26
(43) 2000/07/26

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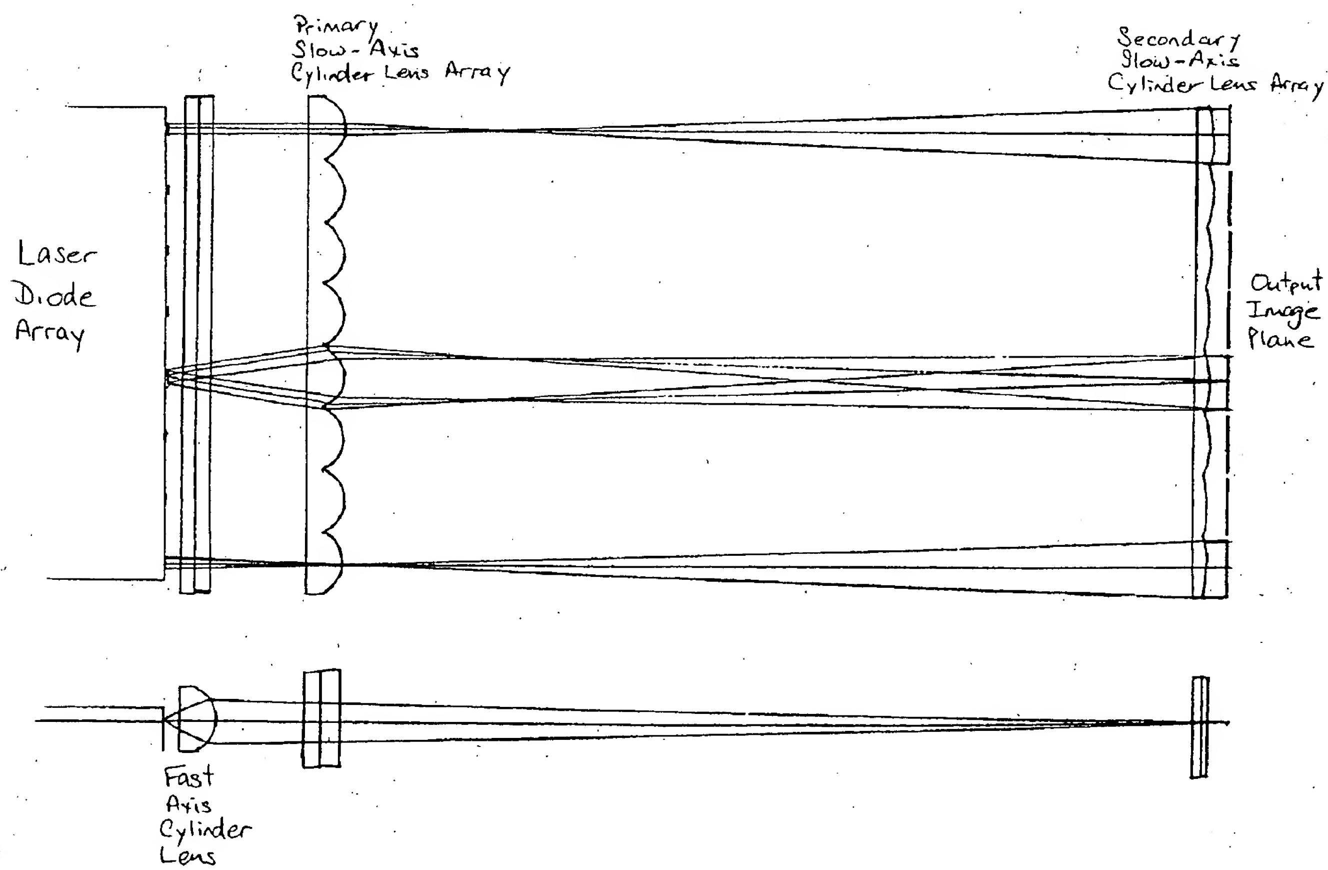
(51) Int.Cl.^{6} G02B 27/09, B41J 2/455, H01S 3/103

(54) **METHODE EN VUE DE COMBINER LA SORTIE D'UN RESEAU DE DIODES LASER EN UN SEUL FAISCEAU TELECENTRIQUE**

(54) **METHOD FOR COMBINING THE OUTPUT OF A LASER DIODE ARRAY INTO A SINGLE TELECENTRIC STRIPE**



Method for combining the output of a Laser Diode Array into a Single Telecentric Stripe

January 14, 1999

High power diode lasers are used in a variety of applications, including the exposure of thermal printing plates. In general, the brightness of these sources is limited by optical and thermal damage limits of the semiconductor materials used. Increased total output power is achieved by extending the length of the emitting aperture, while keeping the width of the stripe at an optimum dimension for efficient lasing action. For power levels that exceed a few Watts of continuous wave output power, the lasers are generally constructed as a monolithic array of light sources, with a substantial separation between the output apertures to limit the thermal load of each emitter. For example, a 20 Watt array may consist of 10 separate lasers, each producing 2 Watts of light from a 150 micron long by 1 micron wide emitting aperture, and spaced on 1000 micron centers (see Figure 1).

The asymmetry of the emitting aperture also results in an asymmetry in the output beam divergence. There are two principle meridional planes, one perpendicular to the emitter stripe which is generally referred to as the fast axis (the strongly diverging beam shown in the elevation view) and the other parallel to the emitter stripe which is referred to as the slow axis (slower diverging beam shown in the plan view). It is well known in the industry that an anamorphic imaging system can be used to nominally match the divergence of the two axes, using crossed cylindrical lenses. The light emanating from the laser is also telecentric, which means that the optical axis of the cone of light diverging from the emitting aperture is always perpendicular to the output facet. This is important for many laser applications where telecentricity is advantageous to reduce the beam divergence and subsequently minimize the size of system and component apertures.

The laser diode source depicted in Figure 1 is shown with 8 separate emitters, with a separation gap that is approximately 6 times larger than the width of each emitter. The sizable gap between emitters is undesirable for a number of imaging applications that require a continuous stripe of light. The present invention describes a method for combining the laser light output of an array of separated emitters into a single, and substantially contiguous stripe. It is important that the optical design provides a high level of optical efficiency, so that the brightness of the individual sources is not compromised. It is also an object of the invention to generate the output stripe with a high level telecentricity to minimize the beam divergence.

Referring now to Figure 2, the optical system consists of the laser diode array, a single fast axis cylinder lens, a primary slow axis cylinder lens array, and a secondary slow axis cylinder lens array. A description of the lens components and their function follows:

> Fast Axis Cylinder Lens: This is a micro-optic cylindrical lens, in common use for coupling the output from laser diodes. These lenses are generally used to collimate the fast axis beam, or to reduce the divergence to match the slow axis. For the present invention, the lens very nearly collimates the light, and forms a highly magnified image of the array of emitters in the fast axis meridian, at the output image plane. The focal length is typically in the 0.3 mm to 1.0 mm range, so that the beam is not allowed to diverge to a significant extent, which helps reduce the overall size of the system, and control aberrations.

> Primary Slow Axis Cylinder Lens Array: This an array of cylinder lenses formed on a single optical substrate. Each cylinder lens in the array will project a magnified image of a single emitter in the slow axis meridian, at the output image plane. The focal length of the cylinder lens is selected to produce the degree of anamorphic compensation that is desired, in conjunction with the fast axis cylinder lens.

> Secondary Slow Axis Cylinder Lens Array: This array is very similar in construction to the previous array, except that the focal length of the lens elements is significantly longer. Again, there is one cylinder lens element that corresponds to each emitter of the laser diode array. This lens array is located just prior to the output image plane, so it has very little effect on the image magnification and aberration performance. It is used to correct the telecentricity of the of the emitter images, to minimize the beam divergence.

The following system design relationships can be used to determine the paraxial component specifications and overall system design performance.

Anamorphic Compression: the ratio between the magnification of the fast axis versus the slow axis is referred to as the anamorphic compression. It should be designed to compensate for the difference in divergence of the two meridional axes, which for laser diodes is typically between 4 and 8.

$$A = M_f / M_s = f_1 / f_0 = (N.A.)_f / (N.A.)_s = \sin\theta_f / \sin\theta_s$$

Slow Axis Magnification: the slow axis magnification should be designed to be very nearly equal to the fill factor of the emitters in the laser diode array, so that a contiguous stripe of laser light is formed at the output image plane.

$$M_s = p / q = D / d$$

the relationship between p, q, and f_1, is determined by the lens equation

$$1/f_1 = 1/p + 1/q \quad \text{or} \quad q = (M_s + 1)f_1$$

Telecentric Compensation: to achieve telecentricity for the final image stripe, the focal length of the secondary cylinder lens array must be equal to the spacing between the lens and the exit pupil from the primary slow axis cylinder lens. Because the source is telecentric, the exit pupil is located at the back focal length of the primary slow axis cylinder lens. Therefore,

$$f_3 = q - f_2$$

As an example, consider the following nominal component specifications:

Laser Diode Emitter Width:	1 micron
Laser Diode Emitter Length:	150 microns
Laser Diode Emitter Spacing:	1000 microns
Laser N.A. (fast axis):	0.55
Laser N.A. (slow axis):	0.08
Fast Axis Collimator (f_1):	0.5 mm.

Using the above equations, the following design parameters can be calculated.

Anamorphic Compression: $A = (N.A.)_f / (N.A.)_s = 0.56 / 0.08 = 7$
Primary Slow Axis Cylinder Lens: $f_1 = f_0 \bullet A = 0.5\text{ mm} \bullet 7 = 3.5\text{ mm.}$
Slow Axis Magnification: $M_s = D / d = 1000 / 150 = 6.7$
Fast Axis Magnification: $M_f = M_s \bullet A = 6.7 \bullet 7 = 47$
Back Focal Distance: $q = (M_s + 1)f_1 = (6.7 + 1)3.5\text{ mm.} = 27\text{ mm.}$
Secondary Slow Axis Cylinder Lens: $f_3 = q - f_2 = 27\text{ mm.} - 3.5\text{ mm.} = 23.5\text{ mm.}$

What is claimed is:

1. An optical system for generating a single linear stripe of light by combining the outputs of a laser diode array. Said optical system comprising of:

   a laser diode array consisting of a plurality of like emitting apertures, fabricated on a single semiconductor substrate and spaced equally in a single row, such that the spacing between centers of said emitting apertures is substantially greater than the length of each of said emitting apertures, and which generates laser light that emanates from each of said emitting apertures along an optical axis with a fast axis plane corresponding to a meridional plane that is perpendicular to said array and a slow axis plane corresponding to a meridional plane that is parallel to said array;

   a singular cylindrical lens element, aligned parallel with said array of emitting apertures, and located along said optical axis so to generate an image of said array of emitting apertures from said fast axis light emanating from each said emitter, at an output image plane, with a magnification substantially greater than unity;

   a primary cylindrical lens array, consisting of a plurality of like cylinder lens elements abutting one another, with the axis of said cylinder lens elements aligned perpendicular to said array of emitting apertures, and with a spacing between said cylindrical lens elements equal to the spacing of said emitting apertures, so that each said cylinder lens element is centered on said optical axis of each said emitting aperture, and positioned to generate an image of said emitting aperture from said slow axis light emanating from each said emitter, at said output image plane, with a magnification very nearly equal to the ratio of said spacing between said emitting apertures and said length of said emitting apertures;

   and a secondary cylindrical lens array, consisting of a plurality of like cylinder lens elements, abutting one another, with the axis of said secondary cylindrical lens elements aligned perpendicular to said array of emitting apertures, and with a spacing between said secondary cylindrical lens elements equal to the spacing of said emitting apertures , so that each said secondary lens element is centered on said optical axis of each said emitting aperture, and positioned very near said output image plane, and with a focal length of said secondary cylindrical lens elements approximately equal to the distance between said output image plane and said primary cylindrical lens array minus the focal length of said primary cylindrical lens elements.

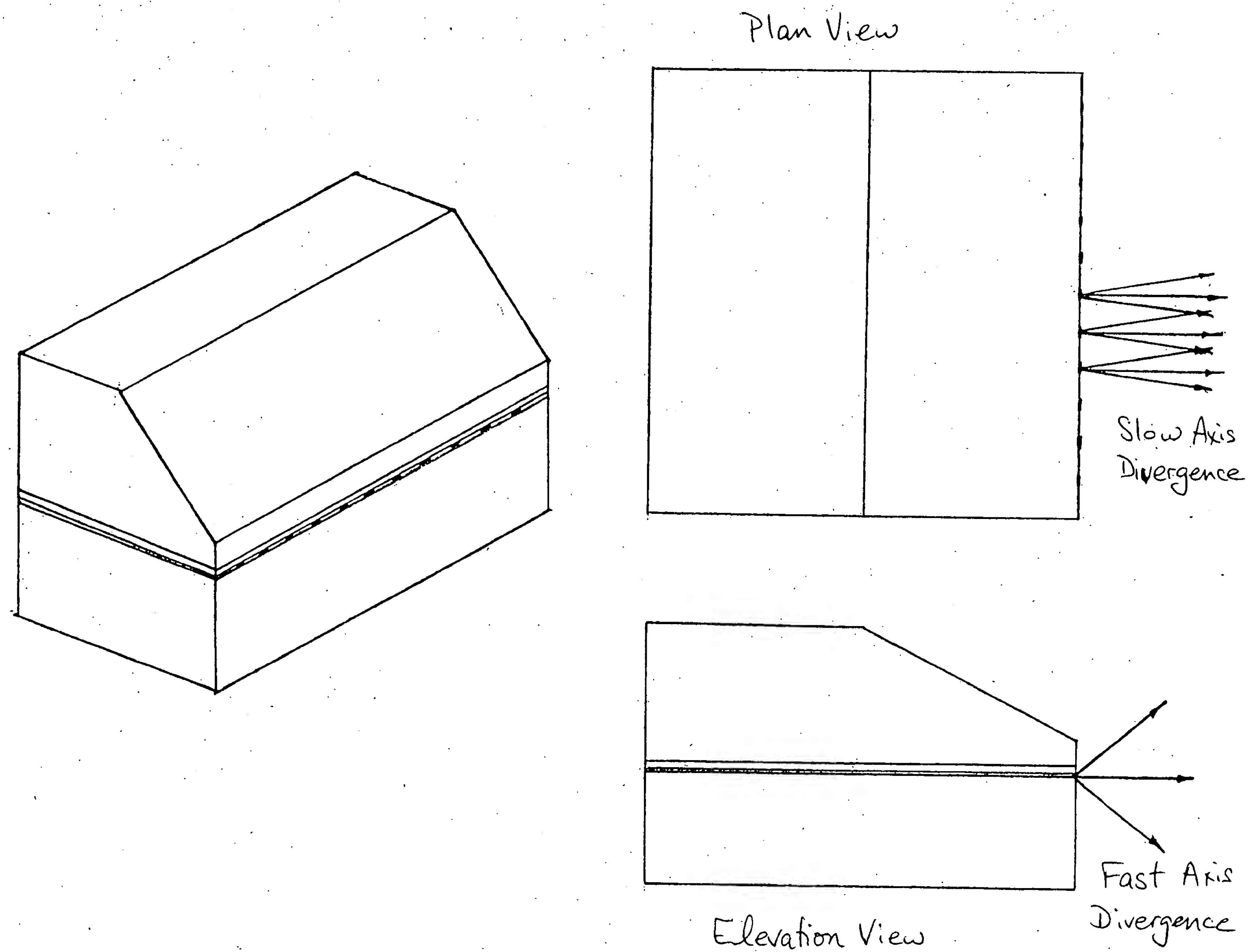

Plan View
Slow Axis Divergence
Fast Axis Divergence
Elevation View

FIGURE 1

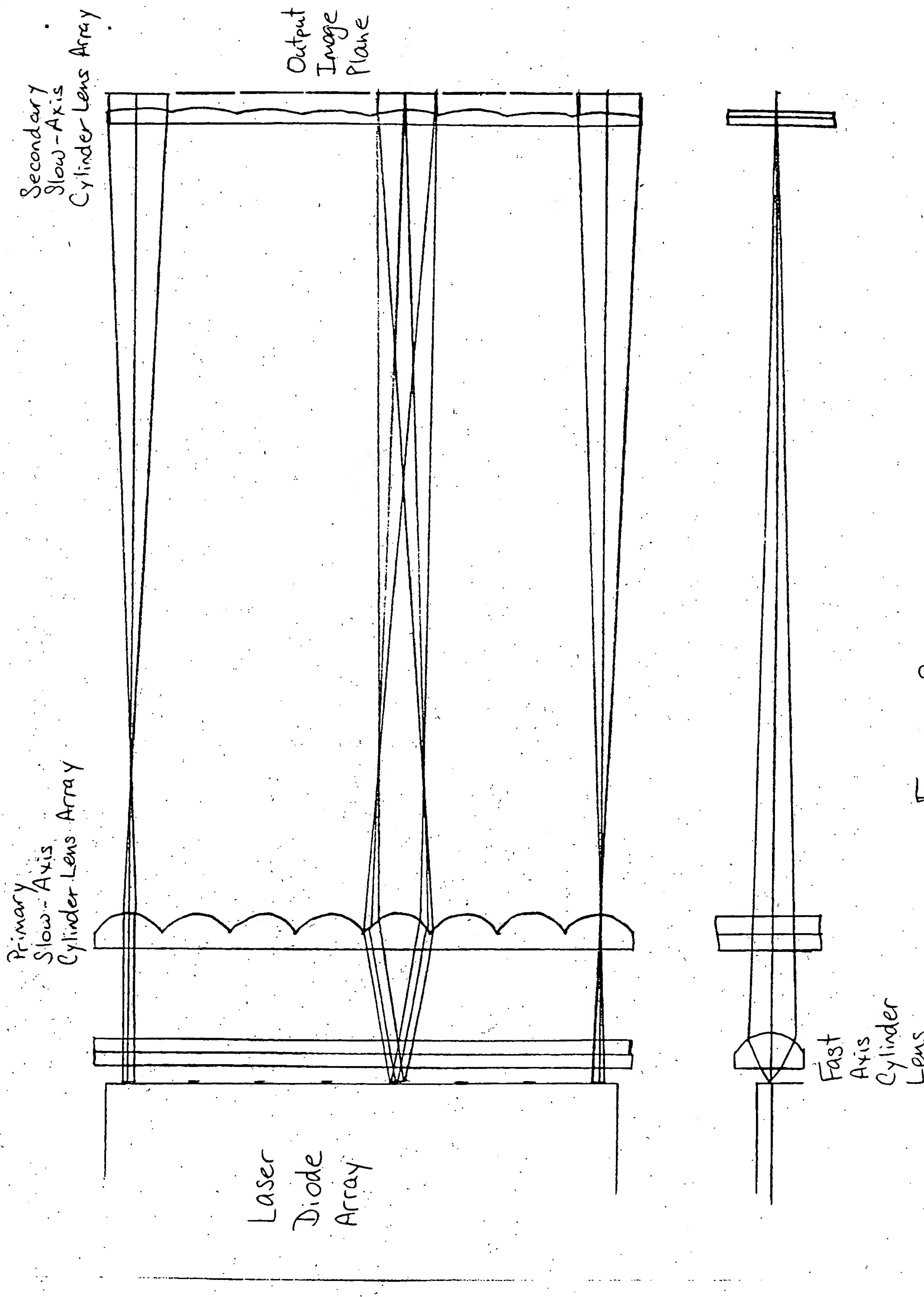

Secondary Slow-Axis Cylinder Lens Array
Output Image Plane
Primary Slow-Axis Cylinder Lens Array
Laser Diode Array
Fast Axis Cylinder Lens

FIGURE 2